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Urbanization and Streams: Studies of Hydrologic Impacts

URBANIZATION AND STREAMS: STUDIES OF HYDROLOGIC IMPACTS

INTRODUCTION

Hydrologic impacts due to urbanization are reported to cause water quality problems such as sedimentation, increased temperatures, habitat changes, and the loss of fish populations. Although there is widespread recognition that these problems are caused by increased runoff volumes and velocities from urbanization and associated increases in watershed imperviousness, much of the reported information has been anecdotal. The summaries and analyses of reports and case studies in this report are intended to go beyond the anecdotal and provide documentation of problems and sources, as well as a foundation for further investigation.

Planners, engineers, water quality specialists, and government officials should find this study a useful introduction to understanding the potential hydrologic impacts of urbanization on streams.

This report was derived from a literature search to find and document physical impacts and indications of water quality problems. United States Geological Survey reports; American Water Resources Association publications; federal, state, and local agency reports; journal articles; conference proceedings; and consultations with experts provided the documentation and case study examples cited in this report.

FINDINGS AND ANALYSIS

Examination of published literature revealed a large amount of anecdotal information that identifies hydrologic impacts on streams caused by increased impervious area (e.g., roads, driveways, parking lots, and rooftops) in urban developments. Figure 1 graphically depicts the impacts of urbanization on stream flow documented in the literature, and Table 1 summarizes the relationship between these changes in flow and other impacts in receiving streams. These impacts include increased frequency of flooding and peak flow volumes, increased sediment loadings, loss

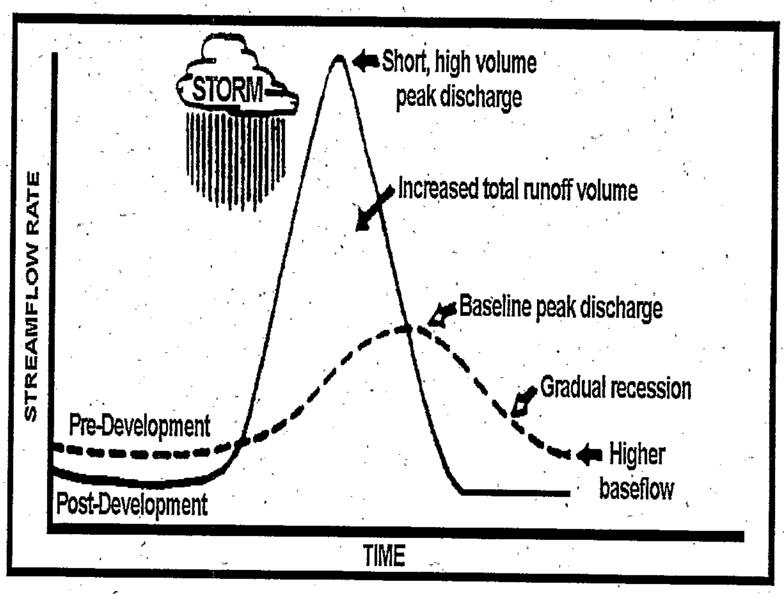

Figure 1. Impacts of urbanization on stream flow (Schueler, 1987).

Table 1. Impacts from Increases in Impervious Surfaces.

Increased Imperviousness leads to:	Resulting Impacts				
	Flooding	Habitat loss (e.g., inadequate substrate, loss of riparian areas, etc.)	Erosion	Channel widening	Streambed alteration
Increased volume	*	*	*	*	*
Increased peak flow	*	*	*	*	*
Increased peak flow duration	*	*	*	*	*
Increased stream temperature		*			
Decreased base flow		*			
Changes in sediment loadings	*	*	*	*	*

of aquatic/riparian habitat, changes in stream physical characteristics (channel width and depth), decreased base flow, and increased stream temperature.[1]

Nine case studies that contained quantitative documentation linking urbanization to hydrologic impacts on streams were identified. They are summarized in Table 2 and are described in the appendix in more detail. It should be noted that some of the impacts identified in Table 2 are inferred from the presence of other indicators. For example, the Valley Stream, Pines Brook, and Bellmore and Massapequa creeks case studies from Long Island, New York, revealed a significant decrease in stream base flow resulting from increased urbanization within the contributing watersheds. Although habitat loss, average stream temperatures, and low dissolved oxygen concentrations were not reported in the study, these impacts typically occur as a result of decreased base flow and can be assumed (Horner et al., 1994; Klein, no date).

[1] For more information on impacts on streams due to urbanization, refer to the following: *Fundamentals of Urban Runoff Management* (Horner et al., 1994), *Site Planning for Urban Stream Protection* (Schueler, 1995), *Effects of Urbanization on Aquatic Resources* (Klein, no date), *Environmental Indicators to Assess Control Programs and Practices* (Claytor and Brown, 1996), *Clearing and Grading Strategies for Urban Watersheds* (Corish, 1995), and several articles in *Watershed Protection Techniques* (Center for Watershed Protection).

Table 2. Results of Case Study Reviews

Case Study	Location	Documented Impacts	Inferred Impacts
Pheasant Branch Basin	Middleton, WI	▪ Stream incision ▪ Increase in bankfull events ▪ Sedimentation	▪ Flooding ▪ Habitat loss ▪ Erosion ▪ Channel widening ▪ Streambed alteration
Holmes Run Watershed	Fairfax, VA	▪ Frequent flooding ▪ Severe stream bank erosion ▪ Sedimentation	▪ Flooding ▪ Habitat loss ▪ Erosion ▪ Channel widening ▪ Streambed alteration
Peachtree Creek	Atlanta, GA	▪ Increased bankfull events ▪ Decreased base flow	▪ Flooding ▪ Habitat loss ▪ Erosion ▪ Channel widening ▪ Streambed alteration
Pipers Creek	Seattle, WA	▪ Increased peak flows ▪ Loss of fish populations ▪ Aesthetic degradation	▪ Flooding ▪ Habitat loss ▪ Erosion ▪ Channel widening ▪ Streambed alteration
Valley Stream, Pines Brook, Bellmore Creek, and Massapequa Creek	Nassau County, NY	▪ Decreased base flow	▪ Habitat loss
East Meadow Brook	Nassau County, NY	▪ Increased peak flows	▪ Flooding ▪ Habitat loss ▪ Erosion ▪ Channel widening ▪ Streambed alteration
Kelsey Creek	Bellvue, WA	▪ Degradation of designated uses ▪ Decreased base flow ▪ Loss of fish populations	▪ Habitat loss ▪ Channel widening
Several Creeks	Dekalb County, GA	▪ Stream enlargement ▪ Stream incision ▪ Increased sediment transport	▪ Habitat loss ▪ Erosion ▪ Channel widening ▪ Streambed alteration
Patuxent River System	Maryland	▪ Increased instream sediment load ▪ Changes in morphology of urban channels	▪ Habitat loss ▪ Erosion ▪ Channel widening

CONCLUSIONS

There are documented case studies that conclusively link urbanization and increased watershed imperviousness to hydrologic impacts on streams. Existing reports and case studies provide strong evidence that urbanization negatively affects streams and results in water quality problems such as loss of habitat, increased temperatures, sedimentation, and loss of fish populations.

However, relatively few case studies have assembled detailed quantitative information to document these phenomena. This is due, in part, to (1) the heavy reliance on engineered approaches to runoff management that can transfer hydrologic impacts (e.g., habitat loss, flooding, channel widening, and erosion) to downstream areas through the construction of paved channels, stormwater pipes, and bank stabilization (e.g., riprap, cutbacks, plantings, bulkheads) and (2) the difficulty and high costs associated with long-term watershed monitoring. Furthermore, the installation of drainage structures, such as pipes and concrete channels, is the final step in removing urban streams from the landscape. Classically, many of these activities have resulted in urban streams being "written off" as virtually nonexistent; therefore, the resulting impacts on water quality and habitats are being ignored.

It is anticipated that in the future the literature will be supplemented with additional studies that document the relationship between urbanization, impervious surfaces, and problems in streams. Future investigations might include Federal Emergency Management Agency (FEMA) floodplain management activities. FEMA trend analysis of widespread changes in 100-year floodplain delineations or increased claims for financial assistance in specific watersheds might add increased evidence of hydrologic impacts due to urbanization. In the meantime, it is hoped that existing information proves sufficient to allow planners, engineers, and local officials to recognize potential hydrologic impacts due to urbanization and to take steps to prevent water quality problems while allowing for sensible development.

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Personal Contacts

Finley, Stuart. Lake Barcroft Watershed Improvement District, Fairfax County, Virginia.

Henry, William. Northern Virginia Soil and Water Conservation District, Fairfax, Virginia.

Muncy, Joy. U.S. Army Corps of Engineer, Fort Belvoir, Virginia.

Powell, Rocky. Baltimore County Department of Environmental Protection, Baltimore, Maryland.

Shreeve, Robert. Maryland Department of Highway Administration, Annapolis, Maryland.

Turlinger, Margaret. Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi.

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APPENDIX: CASE STUDIES

The following case studies demonstrate the impacts that increased flow due to urbanization can have on urban streams. Like urban streams, each case study is unique. The case studies look at different attributes such as habitat, stream stability, and sedimentation. In some cases, where field data did not quantify the impacts, models were applied to estimate impacts. When available, cost information related to the impacts and restoration is included. These summaries reflect the level of detail available in the published reports.

PHEASANT BRANCH BASIN
MIDDLETON, WISCONSIN

Background

The USGS completed a 5-year data collection and modeling study on Pheasant Branch, a stream that drains 24.5 square miles (mi^2) of rolling hills, agricultural land, and rapidly urbanizing areas around Middleton, Wisconsin. The stream is a tributary to Lake Mendota, which requires maintenance dredging because of sedimentation. The area changed in population by 44 percent (8,246 to 11,851) from 1970 to 1980 and is projected to have a population of 18,000 by 2000. Problems of stream channel erosion and suspended sediment have developed in Pheasant Branch because of land use changes in the drainage basin. Urbanization in this area has consisted of residential development as well as industrial and commercial development. The purposes of the study were to demonstrate that urbanization does cause adverse impacts on streams within the watershed and to provide information to city planners and engineers for use when they are evaluating the consequences of development within the drainage basin.

Impacts on Development

During the 1970s, Pheasant Branch exhibited observed impacts from increased urbanization (change in morphology, increased erosion and sediment loadings, lowering of mean streambed elevation by almost 2 feet, and widening of mean channel width by 35 percent). A rainfall runoff model was calibrated and applied to the stream to simulate 68 years of summer flood hydrographs for three conditions—current land use, projected urban development, and complete urban development. Analysis of simulated flood flows indicates that projected urban development would double the mean annual flood peaks in portions of the streams. Complete development of the basin would increase the mean annual flood peaks by a factor of 2.4 without mitigation.

As the watershed became urbanized, significant sedimentation occurred, as well as widening and incision of the stream channel. Table A-1 shows the percent increase of the 2-year flood, bankfull width, and bankfull depth from present conditions to urbanized conditions.

Table A-1. Percent Increase of 2-year Flood, Bankfull Width, and Bankfull Depth from Present Conditions to Urbanized Conditions (based on modeling results).

Site	Projected Urbanization 2-yr Flood	Projected Urbanization Width	Projected Urbanization Depth	Complete Urbanization 2-yr Flood	Complete Urbanization Width	Complete Urbanization Depth
	(Percent Increase from Preurbanization)			(Percent Increase from Preurbanization)		
Site 1	99	40	30	140	60	40
Site 2	324	110	80	361	110	80
Site 3	32	10	10	224	80	60

*Most heavily urbanizing subwatershed.

Source: William R. Krug and Gerald L. Goddard. *Effects of Urbanization on Stream flow, Sediment Loads, and Channel Morphology in Pheasant Branch Basin near Middleton, Wisconsin.* USGS Water Resources Investigations, Report 85-4068. July 1986. U.S. Geological Survey in cooperation with the University of Wisconsin Extension—Geological and Natural History Survey and the City of Middleton.

HOLMES RUN WATERSHED
FAIRFAX COUNTY/FALLS CHURCH, VIRGINIA

Background

The Holmes Run drainage basin is a 14.5-mi^2 watershed with a population of approximately 60,000 (1990). The city of Falls Church composes 14 percent of the watershed; the remaining 86 percent is in Fairfax County. Overall, the watershed is an older suburban region, with the highest densities occurring in Falls Church. In 1995, the Lake Barcroft Watershed Improvement District received Clean Water Act section 319 funds to develop and implement a retrofit program for mitigating the impacts of 30 years of development in the watershed.

Impacts of Development

The flow-related impacts of unmitigated development within the Holmes Run watershed include the following:

- ***Frequent flooding*** from snowmelt and storm runoff. Floods occur several times a year and can be intense enough to endanger the lives of people trapped in cars. Because of urbanization, this flooding has affected private property.

- ***Severe stream bank erosion*** within subwatersheds, which has resulted in severe undercutting of stream banks and deposition of sediment downstream (Figure A-1).

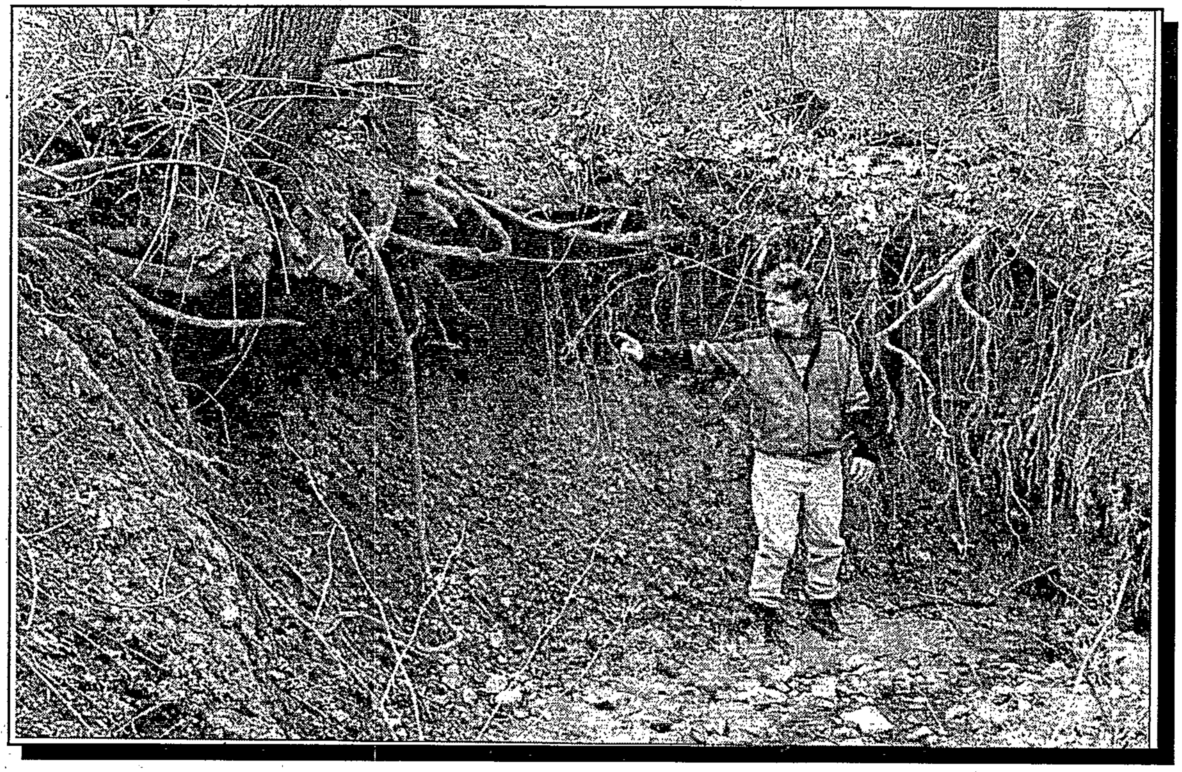

Figure A-1. Severe Stream Bank Erosion in Holmes Run Watershed.

- ***Significant sediment problems*** in Lake Barcroft. Dredging of two internal silt basins must be done four times a year at an average cost of $150,000 for each dredging. Since 1961, approximately 376,000 cubic yards (yd^3) of sediment has been dredged in the watershed at a total cost of more than $2 million.

- ***Debris*** from intense storm scour is washed into Holmes Run and its tributaries, blocking flow and impairing water quality.

Source: Lake Barcroft Watershed Improvement District. *Holmes Run Watershed Best Management Practice Implementation Project.* Final report. Lake Barcroft Watershed Improvement District, Fairfax County, Virginia. 1997.

PEACHTREE CREEK ATLANTA, GEORGIA

Background

The Peachtree Creek watershed near Atlanta, Georgia, is an ideal location to monitor the response of stream flow to urbanization. A major portion of the watershed, covering 86.8 mi^2, lies upstream of a U.S. Geological Survey (USGS) gauging station where stream runoff data have been collected continuously since 1958. This corresponds roughly to the period of rapidly increasing urbanization in the watershed.

Prior to urbanization in the watershed, which began slowly in the early part of the century, the area was covered primarily by wooded land. Early increases in imperviousness were primarily due to conversions of this woodland to buildings or pavement. By the middle of the century the watershed had a substantial amount of impervious cover—about 28 percent in 1958. More rapid urbanization began at about this time, and the rate of conversion to impervious cover increased. By 1968 imperviousness had increased to 35 percent. Population of the area increased rapidly as well—from 215,450 in 1960 to 473,600 in 1985.

Researchers decided to use the stream flow data that had been collected over 30 years in the watershed to determine if correlations between increases in imperviousness and stream flow volume could be found. Stream flow data, annual runoff data, and information on the state of imperviousness in the watershed were collected and analyzed together. The results demonstrated just how closely a change from southern woodland to southern city is related to impacts on streams and rivers.

Results of the Analysis

Annual runoff and rainfall data for the watershed from 1958 to 1988 indicate the urbanization and impacts on streams are closely correlated. During the latter half of those 30 years (1973 to 1988), the analysis indicated that urbanization had resulted in stream runoff volumes even greater than those which had been expected based on the relationship derived from the data. During dry years in the same period, in contrast, the data pointed to a decrease in stream flow during low flow periods as a result of urbanization, to levels below normal. This result was not surprising and is an expected result of urbanization, which typically decreases the quantity of water that seeps into the ground to replenish ground water supplies. It is the level of ground water, not rainwater runoff, that is primarily responsible for keeping streams running during periods of low rainfall. The ground water reserves in the Peachtree Creek watershed had probably dwindled over the years due to progressive urbanization. Increased evaporation during these dry years could also have contributed to the low flows.

Perhaps the most important finding from the data analysis in terms of the effects of urbanization on stream flow was that peak runoff flows for a given intensity of storm increased in the Peachtree Creek watershed as the watershed became more urbanized. That means that the Peachtree Creek today has to carry far more water in—or beyond—its banks during a storm event than it did before urbanization of the surrounding watershed.

Source: Bruce Ferguson and Philip Suckling. Changing Rainfall-Runoff Relationships in the Urbanizing Peachtree Creek Watershed, Atlanta, Georgia. *Water Resources Bulletin* (AWRA). April 1990.

PIPERS CREEK
SEATTLE, WASHINGTON

Background

The Pipers Creek Watershed is located in the Seattle, Washington, area and covers approximately 3 mi^2. The upper reaches of the watershed are 100 percent developed—primarily with shopping centers, residences, and commercial development—with a high percent of impervious surfaces.

The lower reaches of the watershed are surrounded by steep slopes in a park. The creek discharges to Puget Sound with an average 1-year peak flow of 330 cubic feet per second (ft^3/s) and a 100-year event flow of 1,000 ft^3/s. Although no predevelopment rates have been quantified, it is estimated that they did not exceed 20 ft^3/s for the 1-year event. Under natural conditions, it is believed that Pipers Creek was dominated by pools and drops and provided excellent habitat for several aquatic species, including trout and salmon.

Impacts of Development

In the early 1970s the city of Seattle built a storm drain pipe system to serve the heavily developed portion of the watershed. The Pipers Creek watershed averages 10 housing units per acre. This led to peak storm flows in excess of 300 ft^3/s. Because of the development of the watershed and increased flow, boulders originally installed to control runoff impacts downstream became traps for sediment and debris. During low flows, the stream lacked concentrated flows to move sediment through the system. Because of large stormwater volumes over many years, the stream channel was straightened. Due to these conditions, fish populations were restricted by limited quality habitat, limited food, and difficult passage up and down the stream. The stream was also aesthetically unappealing.

Actions Taken

The city has taken actions to restore the stream. This program is based on a relatively low cost maintenance approach ($35,000 for 1 mile of stream) that stabilizes the channel and rebuilds fish habitat. Some of the actions taken include protecting the eroding portions of the stream channel, installing "step-downs" to create pools and riffles for habitat, clearing fish passages, through the boulders, and deepening the channel to allow a fairly steady consolidated stream flow to remove fine sediments.

Sources: Richard Gustav, Douglas Sovern, and Percy Washington. Maintaining Fish Habitat in Urban Streams. *Water Environment and Technology*. June 1994.

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VALLEY STREAM, PINES BROOK, AND BELLMORE AND MASSAPEQUA CREEKS LONG ISLAND, NEW YORK

Background

The USGS conducted a study of the impacts of urbanization on base flow in four urban streams on the southwest shore of Long Island, New York. The purpose of the study was to quantify the changes in base flow in the streams resulting from urbanization. Because of the permeable glacial soils (sand and gravel) in the area, ground water seepage made up approximately 95 percent of the area's stream flow. The balance was from runoff from storm events.

Impacts of Urbanization

The urbanization that began in the 1940s and continued through the 1970s led to construction of stormwater conveyance systems and sanitary sewers. This resulted in more water being discharged to tide and not seeping into the ground to recharge the aquifer, thus reducing base flow to the streams. Table A-2 shows the impact of urbanization on base flow by comparing two streams in each of three areas—an urbanized sewered area, an urbanized unsewered area, and a rural unsewered area. As shown in the table, urbanization since the 1940s has resulted in significant loss of ground water flow to streams in the area.

Table A-2. Average Percent Base Flow of Selected Streams on Long Island by Area.

Years	Urbanized Sewered Area (% Flow from Base Flow)		Urbanized Unsewered Area (% Flow from Base Flow)		Rural Unsewered Area (% Flow from Base Flow)	
	Stream 1	Stream 2	Stream 1	Stream 2	Stream 1	Stream 2
1948-1953	(no data)	86	84	94	96	95
1953-1964	63	69	89	89	95	97
1964-1970	17	22	83	84	96	97

Source: Dale Simmons and Richard Reynolds. Effects of Urbanization on Base Flow of Selected South-Shore Streams, Long Island, New York. U.S. Geological Survey. *AWRA Water Resources Bulletin.* October 1982.

EAST MEADOW BROOK NASSAU COUNTY, LONG ISLAND, NEW YORK

Background

A study was conducted on the southward-flowing East Meadow Brook in Nassau County, Long Island, New York, to determine the impact of increased urbanization on the direct runoff to the stream. The purposes of the study were to relate urban development to the increases in the volume of annual runoff to the stream, to compare hydrograph features of preurbanization and posturbanization, and to compare rainfall-runoff relationships for periods before and after urban development. The East Meadow Brook drainage area covers approximately 31 mi^2. The area experienced intense urbanization from 1944 to 1962. This development included construction of storm sewers that discharge to the stream. The area was developed when the main focus of stormwater management was to move the water out of an area and prevent flooding.

Impacts of Urbanization

The study showed that an increase in the volume of direct runoff closely corresponded to an increase in the area having storm sewers that drained directly to East Meadow Brook. The development area increased by 530 percent from 1943 to 1962. During this same period, annual direct runoff to East Meadow Brook increased by 270 percent. One-hour hydrographs of storms in the watershed showed that the average peak discharge increased from 313 ft^3/s in 1939 to approximately 776 ft^3/s in 1962.

Source: G.E. Seaburn. *Effects of Urbanization on Direct Runoff to East Meadow Brook, Nassau County, Long Island, New York.* U.S. Geological Survey Professional Paper 627-B. U.S. Government Printing Office, Washington, DC. 1969.

KELSEY CREEK
BELLEVUE, WASHINGTON

Background

Kelsey Creek is a heavily urbanized watershed in Bellevue, Washington. Over the years, degradation of its designated uses has occurred.

Impacts of Urbanization

Although degraded water quality has been a factor in the declining quality of Kelsey Creek, aquatic organism impacts are mostly associated with increased peak flow and the resultant sediment carrying capacity and channel instability in the stream. Kelsey Creek has extreme hydrologic responses to storms. Flooding has substantially increased due to urbanization; the peak annual discharge has almost doubled in 30 years, and the flooding frequency also has increased. This has resulted in the greater sediment transport and channel instability. The stream has also exhibited lower base flows (when compared to urbanized streams) between storms. This factor might have affected the stream's ability to flush toxic spills or other dry-weather pollutants from the creek systems. All of these factors might have resulted in a change in the dominant fish species from coho salmon to the less pollutantsensitive cutthroat trout. This lower "flushing" during dry periods might also have reduced the movement of smaller fish and other aquatic organisms through the system.

Source: Robert Pitt. Biological Effects of Urban Runoff Discharges. Presented at the Engineering Foundation conference Urban Runoff and Receiving Systems: An Interdisciplinary Analysis of Impact, Monitoring, and Management, Mt. Crested Butte, Colorado. August 1991.

ATLANTA METROPOLITAN AREA
DEKALB COUNTY, GEORGIA

Background

Observations and studies of several creeks in and around the Atlanta, Georgia, area have demonstrated the impact of increased stormwater flow on urban stream morphology, primarily incision and enlargement of stream channels. Despite city and county stormwater regulations requiring that peak discharges following development be controlled to predevelopment rates for the 2-, 5-, 10-, 25-, 50-, and 100-year storms, degradation is occurring.

Impacts of Development

The following are two documented examples of changes in stream morphology in the Atlanta area:

- A first-order stream that was stable before the construction of a 12-acre apartment complex now exhibits channel enlargement where it receives outfall from a detention pond constructed to control impacts from the development. The detention facility, sized to accommodate peak runoff rates calculated by the rational method, was designed with a maximum storage capacity of 40,000 ft^3. However, abundant vegetative growth in the pond has reduced its capacity, resulting in more water being discharged to the stream. Efforts to reduce the channel degradation have been ineffective.

- When the area was used for agricultural production at the turn of the century, several small gullies formed on hillsides. After the abandonment of agriculture more than 40 years ago, the gullies stabilized. They often contain 30- to 40-year-old trees, which were able to grow because the gullies received only intermittent flows during times of severe rain events. As urbanization increased, these areas became conveyance systems for stormwater from impervious surfaces. Active downcutting is taking place in these areas, resulting in undercut trees, headcuts, and the export of large amounts of sediment.

Source: Nelson R. Nunnaly. Channel Incision in the Atlanta Metropolitan Area. In *Management of Landscapes Disturbed by Channel Incision*, edited by S. Wang, E. Langendoen, and F. Shields, Jr. The University of Mississippi. 1997.

PATUXENT RIVER SYSTEM
MARYLAND

Background

The Patuxent River system was studied by the Maryland Department of Natural Resources in the 1970s because it had both rural and urbanizing areas.

Impacts of Urbanization

The study concluded that subwatersheds within suburbanizing areas are markedly different in physical characteristics and behavior from rural watersheds. Urbanizing basins yield approximately 986.6 tons of sediment/mi^2/yr, compared to 63.7 tons produced by the same area in a rural watershed. Such extensive sediment loads can choke streams, and "sand bars" can occur as far downstream as 3.5 miles. The size and shape of urban channels changed at rates at least three times greater than those found in comparable rural areas.

Source: Helen L Fox. The Urbanizing River: A Case Study in the Maryland Piedmont. In *Geomorphology and Engineering*, edited by D.R. Coates. Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Pennsylvania. 1976.

VARIOUS STREAMS
NORTH CAROLINA PIEDMONT

Background

Historical stream flow data were analyzed for a number of streams in North Carolina. The intent was to see if a correlation could be drawn between low stream flows and urbanization. The data were compared for both urbanizing watersheds and watersheds in areas that are still rural.

Results

While there was some support for the premise that urbanization could lead to low stream flow, the statistical analysis of the data proved inconclusive. It appeared that both urban and rural small streams were experiencing decreasing stream flows over time.

Source: Evett, J.B. *Effects of Urbanization and Land Use Changes on Low Stream Flows.* University of North Carolina, Charlotte, College of Engineering, Department of Civil Engineering. June 1994.